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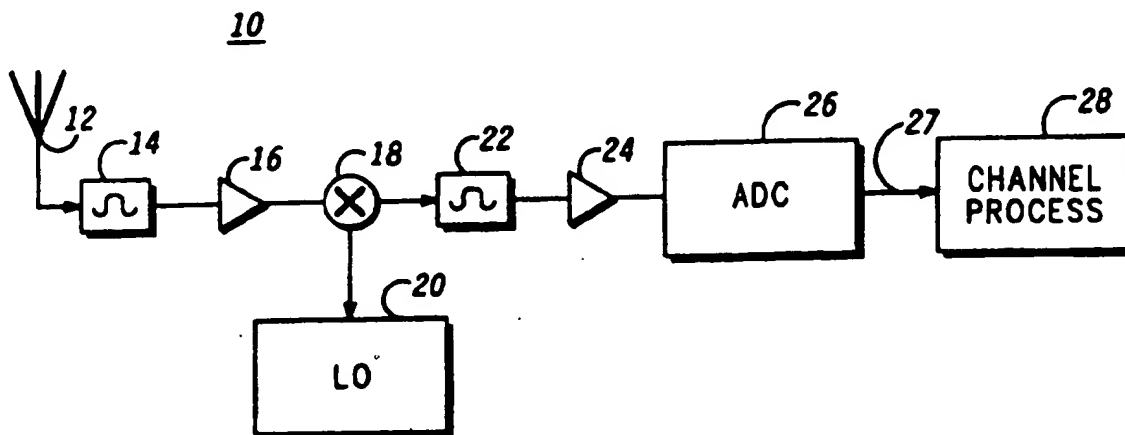
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: PCT/US95/15295 (22) International Filing Date: 22 November 1995 (22.11.95) (30) Priority Data: 08/366,347 29 December 1994 (29.12.94) US (71) Applicant: MOTOROLA INC. [US/US]; 1303 East Algonquin Road, Schaumburg, IL 60196 (US). (72) Inventors: SMITH, Paul, Fielding; 7325 Stonedale Court, North Richland Hills, TX 76180 (US). PINCKLEY, Danny, Thomas; 3714 Dauphine Court, Arlington, TX 76016 (US). (74) Agents: WARREN, Raymond, J. et al.; Motorola Inc., Intellectual Property Dept., 1303 East Algonquin Road, Schaumburg, IL 60196 (US).	(81) Designated States: CA, CN, DE, FI, GB, JP, SE.  Published With international search report. With amended claims.	

(54) Title: SPLIT FREQUENCY BAND SIGNAL DIGITIZER AND METHOD



## (57) Abstract

A split frequency band signal digitizer (10) includes a first mixer (18) for translating a split-band signal (200) about a multiple of the sampling frequency. The split-band signal so translated is then communicated to an analog-to-digital converter (26). The digitized signal is then analyzed to recover an original portion of the split-band signal and a second portion of the signal aliased into a single Nyquist band.

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# SPLIT FREQUENCY BAND SIGNAL DIGITIZER AND METHOD

## Field of the Invention

5       The present invention relates to multi-channel digital transceivers, and more particularly, to a split frequency band signal digitizer and a method of efficiently digitizing split frequency band signals.

**Background of the Invention**

There are numerous advantages to implementing a radio communication system using digital techniques. Notably, there is enhanced system capacity, reduced noise, and reduced hardware and associated power consumption. There has been proposed several digital radio communication systems. For example, there is shown and described in the commonly assigned U.S. Patent Application entitled "Multi-Channel Digital Transceiver and Method" filed on even date herewith and of which the Applicants are co-inventors several preferred embodiments of radio communication systems implementing digital techniques.

Fundamental to the digital radio communication system is the requirement that the received analog radio signal be digitized. The well known Nyquist criteria provides that such digitization is accomplished with minimal error using an analog-to-digital converter (ADC) with a sampling rate greater than twice the bandwidth of the analog signal. In United States Patent No. 5,251,218 a methodology typical of the prior art is disclosed for digitizing an analog radio frequency signal. It will be appreciated, however, where the radio signal occupies a large bandwidth, ADCs

capable of operation at very high sampling rates are required. Such devices, to the extent they are available, are expensive and often suffer reduced performance, i.e., have significant distortion and increased power consumption when operated at high sampling rates.

5       The spectrum allocated to radio communication systems is typically large with respect to the requirements for digitizing. In some radio communication systems, however, although the desired signal occupies a large bandwidth, not all of the bandwidth is occupied by signals of interest. In cellular radio telephone  
10 communication systems, for example, the communication bandwidth is not contiguous. When radio spectrum was initially allocated for cellular radio telephone communications, two contiguous 10 Megahertz (MHz) blocks of spectrum were allocated for "A-band" operators and "B-band" operators, respectively. However, as the  
15 need arose to enhance capacity of the cellular radio communication system, additional bandwidth was required. Unfortunately, large enough blocks of bandwidth adjacent the originally allocated blocks were not available. Hence, additional 2.5 MHz blocks of bandwidth were allocated. The resulting A-band is illustrated in FIG. 2A as an  
20 11 MHz block and a 1.5 MHz block separated by a 10 MHz block occupied by the B-band. So, while the cellular A-band and B-band each have a bandwidth of 12.5 MHz, spectrally, the entire A-band covers 22.5 MHz of bandwidth in two discontinuous portions.

      In order to digitize the A-band, for example, one would need an  
25 ADC capable of operating, according to Nyquist criteria, at least at 45 Mhz or 45 million samples per second (Ms/s), and more reliably at 56Ms/s. Splitting the signal into smaller segments allows the use of multiple ADCs at lower sampling rates. Using multiple ADCs has the disadvantage of requiring more hardware. Furthermore, clock  
30 frequency and higher order harmonics thereof inevitably fall into the frequency band of the signal being digitized. Still another

disadvantage is the amount of digital data handling required to filter, interpolate, compensate for band overlap and sum the resulting multiple digital signals.

Therefore, there is a need for a device and method for  
5 digitizing split frequency band signals which does not require high sampling rates, and does not significantly increase the amount of hardware required for the communication system. Such a device and method are provided by the present invention, and one of ordinary skill in the art will readily appreciate the many advantages and  
10 features of the present invention from the following detailed description and accompanying drawings.

### Brief Description of the Drawings

15 FIG. 1 is a block diagram representation of a split frequency band digitizer in accordance with a preferred embodiment of the present invention;

FIG. 2A is a spectral representation of a split frequency band signal;

20 FIG 2B is a spectral representation of the split frequency band signal shown in FIG. 2A after translation according to a preferred embodiment of the present invention;

FIG 2C is a spectral representation of the split frequency band signal shown in FIG. 2B after converting to a digital signal in  
25 accordance with a preferred embodiment of the present invention; and

FIG 3 is a flowchart illustrating a method of digitizing a split frequency band signal in accordance with a preferred embodiment of the present invention.

30

### Detailed Description of a Preferred Embodiment

Digitizing of a split frequency band analog signal is accomplished in the present invention with both reduced sampling frequency and hardware requirements. The present invention provides for mixing the entire split frequency bandwidth about a reference frequency which will allow for digitizing at a reduced sampling frequency. The reference frequency is chosen such that the segments of the split frequency bandwidth occupy adjacent aliasing bands. Digitizing at a reduced sampling frequency produces a digital signal with the entire split frequency band signal represented in a single Nyquist band of the sampling frequency.

Referring to FIG. 1 a digital radio receiver 10 incorporating the digitizer of the present invention is shown. A split frequency band analog signal is received at antenna 12 and down mixed and signal conditioned through filter 14 and amplifier 16 as is well known in the art. The split frequency band signal is then communicated to mixer 18 where it is frequency translated by a signal from local oscillator 20.

With reference to FIGs. 2A - 2C, a split frequency band signal 200 is shown. Signal 200 is typical of that of the cellular A-band, however, it should be understood that the present invention is applicable to digitizing any type split frequency band analog signal. The result of mixing signal 200 with the reference frequency in mixer 18 is signal 200', FIG. 2B. As can be seen, after mixing, the split frequency band signal is translated such that the split segments of the signal 200' lie about the reference frequency shown as  $f_s/2$ . It will be appreciated that an appropriate local oscillator frequency can be selected for either high side or low side injection, depending upon the split band frequency signal, to translate the signal about the reference signal.

The mixed split frequency band signal is further conditioned through filter 22 and amplifier 24. The translated split band frequency signal is then communicated to analog-to-digital converter (ADC) 26. Analog-to-digital converter 26, digitizes at a sampling rate  $f_s$ , in a known manner, the split frequency band analog signal to produce a digital signal 27. Digital signal 27 is represented in FIG. 2C as 200". As can be seen from FIG. 2C, digitizing signal 200' results in aliasing of the split band segments (shown in phantom) of signal 200", with the aliased segments contained within a Nyquist band of the sampling frequency,  $f_s$ .

In the preferred embodiment of the present invention, the sampling frequency,  $f_s$ , is selected to be approximately 2.5 times the bandwidth of the wider segment of the split band frequency signal. The reference frequency is selected to be approximately half the sampling frequency or a multiple thereof. As will be appreciated, the entire split frequency band signal is digitized using a sampling rate which is less than twice the total spectral bandwidth of the split frequency band signal, e.g., as shown in FIG. 2A. With further reference to FIG. 2C a specific example of selecting the sampling frequency is shown for the cellular A-band. From the spectral chart shown, two observations can be made, first:

$$X + 1.5 + 2Y = 10 \quad (a)$$

and second:

$$Z + 11 + X + 1.5 + Y = f_s/2 \quad (b)$$

from which it can be determined that:

$$f_s = 33.5 + X + 2Z \quad (c)$$

where X, Y and Z are as shown in FIG. 2C, and 11 MHz and 1.5 MHz are the bandwidths of the segments being digitized, respectively.



This relationship is true regardless of the alias band being considered. It can be seen from the above that  $f_s$  can

approach 33.5 Ms/s as compared to 56 Ms/s which would otherwise be required to digitize the cellular A-band. In practical

5 applications,  $f_s$  is dependent on filtering. That is, the X segment must be wide enough to allow an anti-aliasing filter to pass the 11 MHz band but attenuate the 1.5 MHz alias. The Z segment must be big enough such that, after mixing, the image that is generated by

10 sampling can be filtered out. In practice,  $f_s$  can realistically approach 35 Ms/s.

The digital signal 200" is then communicated to channel processors 28. Channel processors operate on signal 200" to recover the digital representation of the entire split frequency band signal. A

15 discussion of such channel processors can be found in the aforementioned U.S. Patent Application entitled "Multi-channel Digital Transceiver and Method". It should be noted that the digital representation of the signal, due to aliasing contains transposed segments of the split frequency band signal. It would, however, be within the skilled artisans knowledge to properly reconstruct the

20 split frequency band signal from these transposed segments.

With reference then to FIG. 3, a method of digitizing a split frequency band signal in accordance with a preferred embodiment of the present invention is shown, 300-308. A split frequency band

25 signal is received, 302, and is mixed 304 such that the translated split frequency band signal segments lie about a reference frequency. The mixed signal is then digitized, 306, producing a digital signal including aliases of the split frequency band signal. The mixed

30 signal is digitized a sampling rate which is less than twice the total bandwidth of the split frequency band signal. The split frequency band signal is then recovered from the digital signal in a channel processor card 308.

As one of ordinary skill the art will appreciated from the foregoing discussion, the present invention provides a digitizer and method which reduces sampling frequency and/or hardware requirements for digitizing a split frequency band signal. The many  
5 features, advantages and fair scope of the present invention is readily discerned from the foregoing discussion and the subjoined claims.

What is claimed is:

## Claims

1. A split frequency signal digitizer comprising:  
a first frequency translator coupled to receive an analog  
5 split frequency band signal, the analog split frequency band signal  
including a first segment having a first bandwidth and a second  
segment having a second bandwidth, the analog split frequency band  
signal having a total bandwidth greater than the sum of the first and  
second bandwidths, the frequency translator producing a frequency  
10 translated signal from the received signal;  
an analog-to-digital converter responsive to the  
frequency translator, the analog-to-digital converter digitizing the  
frequency translated signal by sampling the frequency translated  
signal at a sampling rate less than twice the total bandwidth of the  
15 split frequency band signal to produce a digital signal, the digital  
signal including a digitized version of the first and second segments  
and aliased versions of the first and second segments.
2. The split frequency signal digitizer as in claim 1 further  
20 comprising a processor recovering a digital representation of the  
analog split frequency band signal from the digital signal.
3. The split frequency signal digitizer as in claim 1 wherein the  
first and second segments and at least one of the aliased versions of  
25 the first and second segments are all spectrally located within a  
bandwidth that is less than twice the total bandwidth of the analog  
split frequency band signal.
4. The split frequency signal digitizer as in claim 1 further  
30 comprising analysis means responsive to the analog-to-digital

converter for receiving the digital signal and extracting a digital representation of the analog split frequency band signal.

5           5. A method of digitizing an analog split frequency band signal comprising the steps of:

                  receiving an analog split frequency band signal, the analog split frequency band signal having a first segment with a first bandwidth, a second segment with a second bandwidth, and a total bandwidth greater than the sum of the first and second bandwidths;

10                   frequency translating the received signal to produce a frequency translated signal, such that a reference frequency is located between frequencies associated with frequency translated versions of the first segment and the second segment in the frequency translated signal; and

15                   digitizing the frequency translated signal by sampling the frequency translated signal at a sampling rate less than twice the total bandwidth of the analog split frequency band signal to produce a digital signal, the digital signal including a digital representation of the first and second segments and aliased versions of the first and  
20                   second segments.

                  6. The method of digitizing an analog split frequency band signal as in claim 5 wherein the digital representation of the first and second segments and at least one of the aliased versions of the first  
25                   and second segments are located within a bandwidth that is less than twice the total bandwidth of the split frequency band signal.

7. The method of digitizing an analog split frequency band signal as in claim 5 wherein the reference frequency is about one half of the sampling rate.

5

8. The method of digitizing an analog split frequency band signal as in claim 7 wherein at least one of the aliased versions of one of the first and second segments are contained within a Nyquist band based on the sampling rate.

10

9. The method of digitizing an analog split frequency band signal as in claim 5 wherein the step of frequency translating the analog split frequency band signal comprises translating the analog split frequency band signal about an integer multiple of a Nyquist frequency of the analog split frequency band signal.

15

10. A digital receiver comprising:

a receiver detecting an analog split frequency signal including a first segment having a first bandwidth and a second segment having a second bandwidth, the analog split frequency signal having a total bandwidth greater than the sum of the first and second bandwidths; and

20

an analog-to-digital converter responsive to the receiver, the analog-to-digital converter digitizing the analog split frequency signal by sampling the analog split frequency signal at a sampling rate less than twice the total bandwidth of the analog split frequency signal to produce a digital signal, the digital signal including a digitized version of the first and second segments and aliased versions of the first and second segments.

25

## AMENDED CLAIMS

[received by the International Bureau on 6 May 1996 (06.05.96);  
original claim 1 amended; remaining claims unchanged (3 pages)]

1. A split frequency signal digitizer comprising:
  - a first frequency translator coupled to receive an  
5 analog split frequency band signal, the analog split frequency  
band signal including a first segment having a first bandwidth  
and a second segment having a second bandwidth, the analog  
split frequency band signal having a total bandwidth greater  
than the sum of the first and second bandwidths, the frequency  
10 translator producing a frequency translated signal from the  
received signal, the frequency translated signal having  
substantially the same total bandwidth as the total bandwidth  
of the analog split frequency band signal;  
an analog-to-digital converter responsive to the  
15 frequency translator, the analog-to-digital converter digitizing  
the frequency translated signal by sampling the frequency  
translated signal at a sampling rate less than twice the total  
bandwidth of the split frequency band signal to produce a  
digital signal, the digital signal including a digitized version of  
20 the first and second segments and aliased versions of the first  
and second segments.
2. The split frequency signal digitizer as in claim 1  
further comprising a processor recovering a digital  
25 representation of the analog split frequency band signal from  
the digital signal.
3. The split frequency signal digitizer as in claim 1  
wherein the first and second segments and at least one of the  
30 aliased versions of the first and second segments are all  
spectrally located within a bandwidth that is less than twice the  
total bandwidth of the analog split frequency band signal.

4. The split frequency signal digitizer as in claim 1 further comprising analysis means responsive to the analog-to-digital converter for receiving the digital signal and extracting a digital representation of the analog split frequency band signal.

5

5. A method of digitizing an analog split frequency band signal comprising the steps of:

receiving an analog split frequency band signal, the  
10 analog split frequency band signal having a first segment with a first bandwidth, a second segment with a second bandwidth, and a total bandwidth greater than the sum of the first and second bandwidths;

frequency translating the received signal to produce  
15 a frequency translated signal, such that a reference frequency is located between frequencies associated with frequency translated versions of the first segment and the second segment in the frequency translated signal; and

digitizing the frequency translated signal by  
20 sampling the frequency translated signal at a sampling rate less than twice the total bandwidth of the analog split frequency band signal to produce a digital signal, the digital signal including a digital representation of the first and second segments and aliased versions of the first and second segments.

25

6. The method of digitizing an analog split frequency band signal as in claim 5 wherein the digital representation of the first and second segments and at least one of the aliased versions of the first and second segments are located within a  
30 bandwidth that is less than twice the total bandwidth of the split frequency band signal.

7. The method of digitizing an analog split frequency band signal as in claim 5 wherein the reference frequency is about one half of the sampling rate.

5

8. The method of digitizing an analog split frequency band signal as in claim 7 wherein at least one of the aliased versions of one of the first and second segments are contained within a Nyquist band based on the sampling rate.

10

9. The method of digitizing an analog split frequency band signal as in claim 5 wherein the step of frequency translating the analog split frequency band signal comprises translating the analog split frequency band signal about an integer multiple of a Nyquist frequency of the analog split frequency band signal.

15

10. A digital receiver comprising:

a receiver detecting an analog split frequency signal including a first segment having a first bandwidth and a second segment having a second bandwidth, the analog split frequency signal having a total bandwidth greater than the sum of the first and second bandwidths; and

an analog-to-digital converter responsive to the receiver, the analog-to-digital converter digitizing the analog split frequency signal by sampling the analog split frequency signal at a sampling rate less than twice the total bandwidth of the analog split frequency signal to produce a digital signal, the digital signal including a digitized version of the first and second segments and aliased versions of the first and second segments.

30



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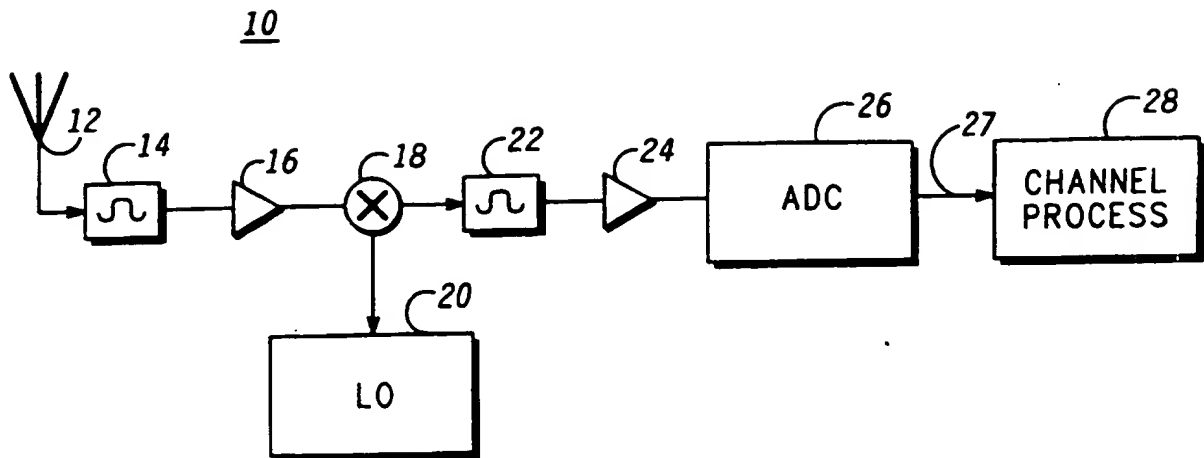


FIG. 1

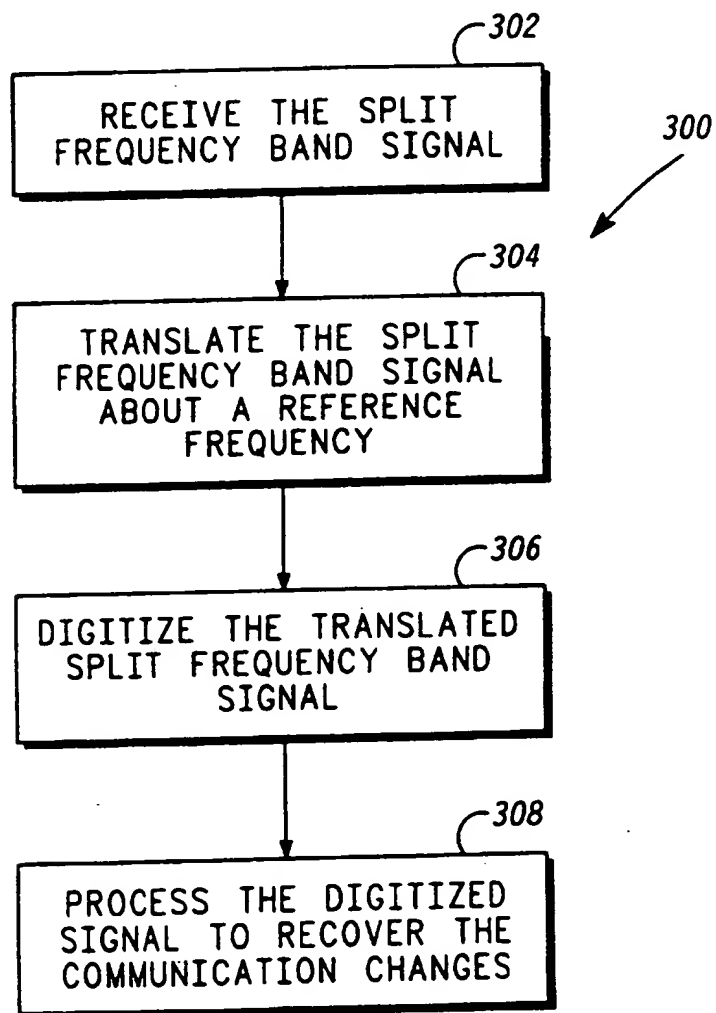


FIG. 3

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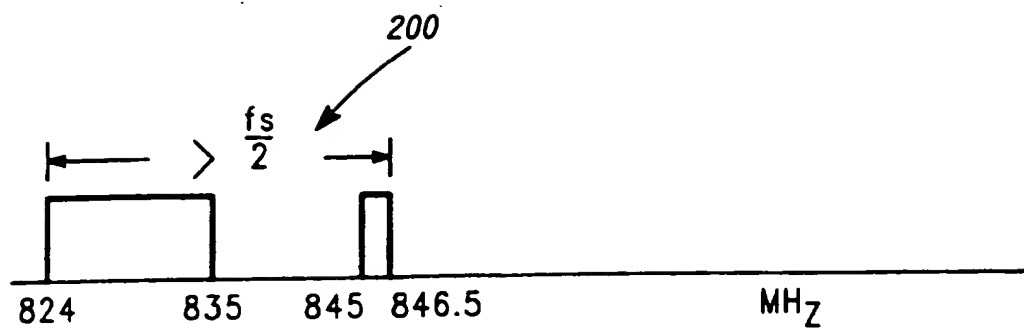


FIG. 2A

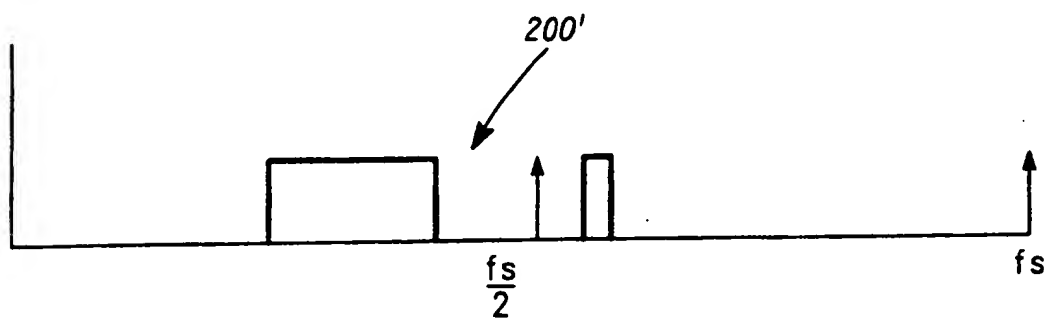


FIG. 2B

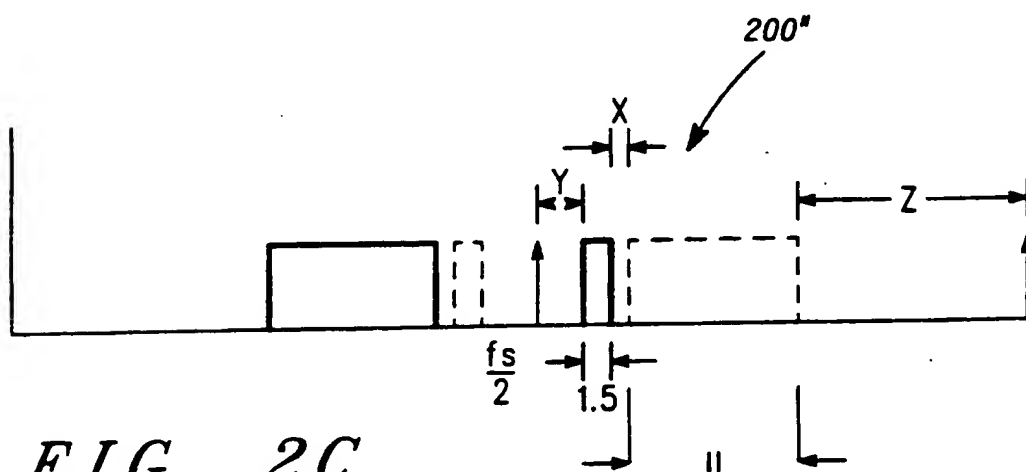


FIG. 2C

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US95/15295

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H03M 1/12; H04B 1/26; H04L 5/06

US CL : 375/316; 455/313; 341/155

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/316; 455/313, 131; 341/155

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- A	US, A, 5,280,636 (KELLEY ET AL) 18 January 1994, entire document, especially figs. 1 and 3, cols. 2-3 and 6.	1-4, 10 ----- 5-9
A, P	US, A, 5,410,569 (HALOZAN) 25 April 1995, fig. 1A.	1-10
A, P	US, A, 5,387,913 (PARK ET AL) 07 February 1995, abstract and fig. 1.	1-10
A	US, A, 3,609,555 (VAN BLERKOM ET AL) 28 September 1971, fig. 1.	1-10
A	EP, A, 0 529 183 (BLAUPUNKT-WERKE GMBH) 03 March 1993, entire document.	1-10

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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* O* document referring to an oral disclosure, use, exhibition or other means		
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Date of the actual completion of the international search

06 FEBRUARY 1996

Date of mailing of the international search report

04 MAR 1996

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## INTERNATIONAL SEARCH REPORT

International application No.  
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,251,218 (STONE ET AL) 05 October 1993, entire document, especially, figs. 4-6.	1-10

# INTERNATIONAL SEARCH REPORT

International Application No.  
PCT/US95/15295

## B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

APS

search terms: receiver, split or multiple bands, analog to digital conversion, digitizer, quantizer, frequency translation, mixing, heterodyning, downconversion, aliasing

# (12) UK Patent Application (19) GB (11) 2 301 500 (13) A

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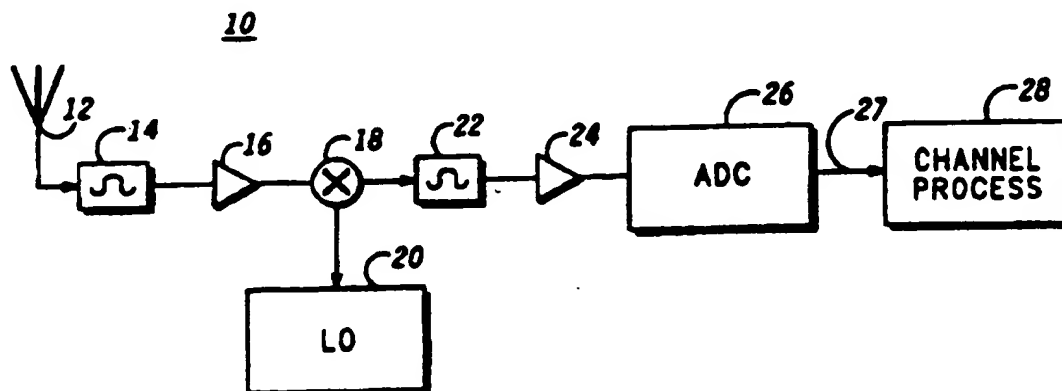
(56) Documents Cited by ISA  
EP 0529183 A1 US 5410569 A US 5387913 A  
US 5280636 A US 5251218 A US 3609555 A

(58) Field of Search by ISA  
U S Classification: 375/316; 455/313, 131; 341/155;  
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## (54) Split frequency band signal digitizer and method

(57) A split frequency band signal digitizer (10) includes a first mixer (18) for translating a split-band signal (200) about a multiple of the sampling frequency. The split-band signal so translated is then communicated to an analog-to-digital converter (26). The digitized signal is then analyzed to recover an original portion of the split-band signal and a second portion of the signal aliased into a single Nyquist band.



GB 2 301 500 A